The Transformative Potential of Distribution Markets: A Rigorous Analysis of Applications, Comparative Utility, and Novel Capabilities

1. Introduction

1.1. The Emergence of Distribution Markets

Financial markets have historically evolved mechanisms to price uncertainty and facilitate risk transfer. Traditional instruments often focus on specific aspects of future outcomes – futures contracts price the expected value of an underlying asset, while options derive value primarily from its expected volatility. Prediction markets extended this by allowing direct trading on the probability of discrete events.[1] However, a significant gap remains: the ability to efficiently trade and express nuanced views on the *entire probability distribution* of events with continuous outcomes. Distribution markets represent a novel financial primitive designed to fill this void, enabling participants to trade contracts whose value is intrinsically linked to the probability density function (PDF) of a future continuous variable.[3] This contrasts sharply with existing market structures that typically yield only point estimates (like expected values from futures) or limited distributional information (like variance from options). The conceptual framework proposed by Paradigm, involving a constant function market maker operating over payoff functions, serves as a foundational example of how such markets might be constructed.[3]

1.2. Core Hypothesis and Motivation

The central hypothesis motivating the exploration of distribution markets is that these mechanisms possess a transformative potential far exceeding that of simple prediction markets. It is posited that well-functioning distribution markets could not only replicate or substantially enhance existing financial instruments and market expressions but also unlock entirely new paradigms for risk management, speculation, and the aggregation of dispersed information [User Query]. This investigation is spurred by the observation that current financial and betting markets often rely on imperfect proxies or complex, opaque instruments to manage exposures related to complex, non-standard risks, such as geopolitical events, technological breakthroughs, or climate change impacts.[5] The limitations inherent in these existing approaches – including basis risk, lack of transparency, counterparty exposure, and insufficient expressiveness – underscore the need for more direct and sophisticated market mechanisms. Distribution markets, by allowing participants to trade the shape of probability itself, offer a potentially powerful solution.

1.3. Research Objectives and Scope

This report undertakes an exceptionally rigorous and comprehensive investigation into the potential applications, comparative utility, and novel capabilities of distribution markets. The core objectives are:

1. To analyze the fundamental mechanics of distribution markets, drawing upon foundational concepts like the Paradigm proposal [3] and relevant market microstructure theory.
2. To rigorously evaluate the capacity of distribution markets to replicate the payoff profiles and risk characteristics (including sensitivities analogous to option Greeks) of standard derivatives like options, futures, and swaps, comparing their properties such as capital efficiency and basis risk.[13]
3. To assess whether distribution markets offer superior mechanisms for expressing views on, or hedging against, complex event risks (geopolitical, technological, climate-related) compared to the use of traditional financial proxies.[5]
4. To identify specific areas within existing financial and betting markets (e.g., bespoke OTC derivatives, structured products [7], parimutuel pools [8]) that could be significantly augmented or displaced by distribution markets, justifying claims of superiority based on factors like transparency, expressiveness, efficiency, and counterparty risk mitigation.[28]
5. To propose and elaborate on distinct, novel market applications uniquely enabled by the ability to trade arbitrary probability distributions, including concepts such as higher-moment trading, complex distribution-contingent claims, model-based hedging, and advanced information aggregation techniques.[33]
6. To conduct a comparative analysis of fundamental market properties—leverage, inherent optionality, liquidity dynamics, price impact, and settlement mechanisms—contrasting distribution markets with established market structures.[3]
7. To maintain a critical perspective by thoroughly evaluating the theoretical limitations and practical challenges associated with distribution markets, including user complexity, market manipulation potential, regulatory hurdles, and computational demands.[24]
8. To synthesize these findings into a coherent assessment of the overall transformative potential of distribution markets relative to the existing financial landscape.

The analysis presented herein aims for theoretical depth and mathematical precision where applicable, grounded in established financial and economic principles while exploring the frontiers of market design.

1.4. Structure of the Report

The report proceeds as follows: Section 2 details the core mechanics of distribution markets, contrasting continuous outcome frameworks with traditional discrete markets and exploring the underlying Constant Function Market Maker (CFMM) and Market Scoring Rule (MSR) formalisms. Section 3 provides a rigorous analysis of how distribution markets can replicate and potentially enhance standard financial derivatives and hedging functions. Section 4 identifies specific existing markets, such as those for structured products and parimutuel betting, that distribution markets might augment or displace due to inherent advantages. Section 5 proposes and elaborates on several novel applications uniquely enabled by the ability to trade distributional shapes and features. Section 6 undertakes a comparative analysis of intrinsic market properties like leverage, optionality, liquidity, price impact, and settlement. Section 7 offers a critical evaluation, detailing the significant theoretical and practical challenges facing the development and adoption of distribution markets. Finally, Section 8 synthesizes the findings, offering a concluding perspective on the transformative potential and future trajectory of this nascent market structure.

2. The Mechanics of Distribution Markets

Understanding the potential of distribution markets requires a firm grasp of their underlying mechanics, which represent a significant departure from traditional market structures designed for discrete outcomes or simple point estimates. This section delves into the foundational concepts, the core market-making frameworks (CFMMs and MSRs), payoff structures, and collateralization requirements.

2.1. Foundational Concepts: From Discrete to Continuous Outcomes

Traditional prediction markets, often implemented as betting exchanges or information markets, allow participants to trade contracts whose payoff is contingent on the occurrence of specific, discrete future events.[1] For example, a contract might pay $1 if a particular candidate wins an election and $0 otherwise. The market price of such a contract is typically interpreted as the collective belief or probability assigned to that outcome by market participants.[1] These markets have demonstrated remarkable forecasting accuracy in various domains [2], often outperforming traditional polls or expert opinions.[2] Their success stems from incentivizing participants with relevant information to reveal their beliefs through trading.[26]

However, many real-world phenomena involve outcomes that are continuous rather than discrete – for instance, the future price of an asset, the magnitude of climate change, the completion time of a project, or the market share of a new technology.[3]

Applying traditional prediction market structures to such scenarios is problematic. One approach is to discretize the continuous outcome space into a finite set of "buckets" or ranges (e.g., "Price between $100-$110", "Price between $110-$120"). While feasible, this approach is inherently limiting. It forces participants to express beliefs over predefined, often arbitrary ranges, losing the nuance of the underlying continuous distribution. Furthermore, the choice of bucket boundaries can significantly influence market behavior and efficiency.

Distribution markets aim to overcome these limitations by designing mechanisms that allow participants to trade directly on the *entire probability distribution* of a continuous outcome variable.[3] Instead of betting on a specific outcome or range, traders can express their beliefs about the likelihood of *every* possible outcome across the continuous spectrum. This requires a fundamental shift from trading discrete claims to trading representations of functions. As proposed by Paradigm, a trader's position can be conceptualized as a function $f(x)$, where x represents a possible outcome in the continuous space (e.g., a real number), and $f(x)$ denotes the payoff the trader receives if the outcome x is realized.[3] The market mechanism then aggregates these individual position functions to form a market-implied probability distribution, represented by the aggregate function across all traders. This allows for the elicitation and trading of much richer information than simple point estimates or probabilities of discrete events, capturing the market's view on variance, skewness, modality, and other features of the distribution.[46]

2.2. The Constant Function Market Maker (CFMM) Framework

A key innovation enabling distribution markets is the extension of the Constant Function Market Maker (CFMM) concept, widely used in Decentralized Finance (DeFi) for token swaps [59], to operate over functions rather than discrete token quantities.[3]

In a standard CFMM for n discrete assets (like Uniswap [80]), a liquidity pool holds reserves $R = (R_1,..., R_n)$ of these assets. Trades $\Delta = (\Delta_1,..., \Delta_n)$ (where positive Δ_i means the trader receives asset i, negative means they tender it) are permitted only if a *trading function* (or invariant) ϕ remains constant: $\phi(R - \Delta) = \phi(R)$.[81] The shape of the level sets defined by $\phi(R) = constant$ determines the relative prices of the assets. Popular examples include the constant product function $\phi(R) = \Pi R_i$ (Uniswap V2) [61] and the constant sum function $\phi(R) = \Sigma R_i$.[61]

Paradigm extends this to the continuous outcome setting by defining the "assets" as infinitesimal claims on each possible outcome x.[3] A trader's aggregate holding is represented by the function $f(x)$, indicating the quantity of claims held for outcome x. The AMM itself maintains a state defined by the aggregate function $f(x)$ bought by

traders and an initial backing collateral b. The AMM's implied holding function is $h(x) = b - f(x)$. The invariant chosen is based on the L2 norm of the traders' aggregate function:

$$||f||_2 = \sqrt{(\int f(x)^2 \, dx)} = k$$

where k is a constant determined by the initial state and liquidity.[3] When a trader wishes to change the market's implied distribution from $f(x)$ to a new function $g(x)$, their trade is effectively $\Delta f(x) = g(x) - f(x)$. This trade is permissible if the new aggregate function $g(x)$ satisfies the invariant $||g||_2 = k$. The cost of this trade is determined by the change in collateral required (discussed in Section 2.5).

The market price, or more accurately, the market's implied PDF $p(x)$, is related to the aggregate function $f(x)$ held by traders. In the Paradigm formulation, the instantaneous price to acquire an infinitesimal amount of the outcome token for x is related to the AMM's holding function $h(x)$. Intuitively, regions where $f(x)$ (and thus the implied probability) is high are more "expensive" to push higher, and regions where it is low are "cheaper," governed by the constraint imposed by the L2 norm invariant. The exact relationship between $f(x)$ and the implied PDF $p(x)$ depends on the specific parameterization and the liquidity parameter b, but $f(x)$ essentially represents a scaled version of the market's implied PDF.

This functional CFMM approach provides a mathematically rigorous way to define prices and facilitate trades over continuous distributions. It inherits desirable properties from the broader CFMM literature, such as path independence (for fee-free versions) and the potential for axiomatic derivation based on desirable trading properties.[83] Research into CFMM axioms has shown that desirable properties often lead to concave, nondecreasing, and homogeneous trading functions, providing a theoretical underpinning for specific choices like the L2 norm or other functional invariants.[83]

2.3. Market Scoring Rules (MSRs) as an Alternative/Equivalent Framework

An alternative, yet formally equivalent, approach to designing markets for information aggregation, particularly suited for sequential trading, is the use of Market Scoring Rules (MSRs).[34] MSRs adapt the concept of proper scoring rules, which are functions designed to incentivize individuals to truthfully report their probabilistic beliefs.[66]

A proper scoring rule $S(r, i)$ assigns a score to an agent who reports a probability distribution $r = (r_1, \dots, r_n)$ over n outcomes, if outcome i subsequently occurs. A scoring rule is *strictly proper* if the expected score $E_{i \sim p} = \Sigma_i \, p_i \, S(r, i)$ is uniquely maximized

when the reported distribution *r* matches the agent's true belief *p*.[66] Common examples include the Quadratic Scoring Rule (QSR) and the Logarithmic Scoring Rule (LSR).[86] For LSR, $S(r, i) = a_i + b \log(r_i)$ [66], and for QSR, $S(r, i) = a_i + 2br_i - b\, \Sigma_{\square}\, r_{\square}^{2}$.[86]

Hanson's key insight was to adapt these for a market setting.[86] In an MSR, a market maker maintains a current probability distribution *p_{t-1}*. When a new trader arrives, they report their belief *p_t*. The market maker pays the *previous* trader based on the score *S(p_{t-1}, i)* if outcome *i* occurs, and the *new* trader pays the market maker based on the score *S(p_t, i)*. The net payoff to the new trader *t* is effectively *S(p_t, i) - S(p_{t-1}, i)*.[72] For myopic, risk-neutral traders, the optimal strategy is to report their true belief *p_t*, thus moving the market price to match their belief.[90] The most common MSR is the Logarithmic Market Scoring Rule (LMSR), whose cost function for changing the net shares outstanding *s* is given by $C(s) = b \ln(\Sigma_i \exp(s_i/b))$, where *b* is a liquidity parameter controlling price sensitivity.[89] The payoff to a trader changing the implied probabilities from *p* to *p'* is $b \log(p'_i/p_i)$ if outcome *i* occurs.[49] The Quadratic Market Scoring Rule (QMSR) offers an alternative with different properties, notably uniform liquidity across the probability spectrum.[88]

Crucially, a formal equivalence exists between MSRs (viewed as cost-function-based markets) and CFMMs.[14] Any cost function $C(q)$ derived from a proper scoring rule can be transformed into a concave potential function $\phi(q) = -C(-q)$ for an equivalent CFMM. Conversely, any sufficiently well-behaved CFMM potential function $\phi(q)$ corresponds to a convex cost function $C(q) = \inf \{c \mid \phi(c\mathbf{1} - q) \geq \phi(q_0)\}$, where **1** represents the "grand bundle" of one unit of each outcome security (equivalent to $1 cash).[14]

This equivalence reveals a deep connection between mechanisms designed for efficient trading and those designed for truthful information elicitation. The desirable properties sought in CFMMs (e.g., axioms leading to concave potential functions ensuring responsiveness to demand [83]) map directly onto the properties required for MSRs to be incentive-compatible (e.g., convexity of the cost function derived from a proper scoring rule [49]). This duality suggests that a market mechanism that efficiently facilitates trade, based on sound microeconomic principles, inherently possesses the structure needed to effectively aggregate and reveal beliefs, and vice versa. This provides a unified theoretical lens through which to analyze and design distribution markets, whether conceptualized via functional CFMMs or extensions of MSRs to continuous outcome spaces.

2.4. Payoff Structure and Settlement

The fundamental payoff principle in a distribution market operating over a continuous outcome space *X* is straightforward: if the definitive outcome of the event is determined to be x_o, a trader holding a position represented by the function *f(x)* receives a payoff of $f(x_o)$ dollars (or units of the collateral asset).[3] The trader's profit or loss is then $f(x_o) - Cost(f)$, where *Cost(f)* represents the net cost incurred to establish the position *f(x)* through interactions with the AMM.

The critical step is the *settlement process*, which involves determining the final outcome x_o and distributing payoffs accordingly. Given the often complex or non-financial nature of events suited for distribution markets (e.g., technological milestones, climate metrics, geopolitical states), determining x_o typically requires an external *oracle*.[3] An oracle acts as a trusted source of truth, observing the real-world event and reporting the definitive outcome value x_o to the market mechanism.[3]

In the context of blockchain-based distribution markets, this oracle would likely be a decentralized oracle network (DON) or a specific, pre-agreed data feed integrated via smart contract.[3] The reliability, accuracy, and tamper-resistance of the oracle are paramount; oracle failure or manipulation represents a significant systemic risk for the market.[94] Once the oracle reports x_o, the settlement can be automated via smart contracts. The contract holding the AMM logic and trader positions would calculate $f(x_o)$ for each trader (or the equivalent payoff based on discrete outcome tokens) and distribute the collateral accordingly.[3]

Blockchain technology offers significant advantages for settlement:

- **Automation:** Smart contracts execute the payoff calculations and transfers automatically based on the oracle input, removing intermediaries and potential delays.[63]
- **Transparency:** All trades, positions (*f(x)* or token holdings), AMM state, and the final settlement transaction are recorded immutably on the public ledger.[31]
- **Reduced Counterparty Risk:** Collateral is typically held within the smart contract system, and settlement logic is enforced by code, minimizing the risk of one party failing to meet their obligations (though smart contract bug risk remains).[31]
- **Atomicity:** Blockchain settlement can often be atomic, meaning the entire settlement process (determining winners, calculating payoffs, transferring funds) happens as a single, indivisible transaction, preventing partial failures.[98]

Challenges remain, particularly around defining unambiguous resolution criteria for complex events and ensuring oracle security and reliability.[63] Some research explores "self-resolving" markets where payoffs depend on the reports of other participants

rather than an external ground truth, potentially useful when objective resolution is impossible, though introducing different incentive complexities.[33]

2.5. Collateralization and Risk Management

Ensuring solvency is critical for any market mechanism, and distribution markets, particularly those based on the Paradigm CFMM model, employ a specific collateralization scheme.[3] When a trader executes a trade that shifts the market's aggregate position function from $f(x)$ to $g(x)$, they must post collateral sufficient to cover the maximum possible loss incurred by this change in position. The change in the trader's position is $\Delta f(x) = g(x) - f(x)$. The payoff from this change, if outcome x_o occurs, is $\Delta f(x_o)$. The maximum potential loss occurs at the outcome x that minimizes this payoff. Therefore, the required collateral is:

$$\text{Collateral} = -\min_x(g(x) - f(x)) = \max_x(f(x) - g(x))$$

This ensures that even in the worst-case outcome for the trader, the collateral they posted is sufficient to cover their loss relative to the previous state $f(x)$.[3] The AMM itself is backed by initial collateral b, ensuring it can fulfill its side of the payoff $h(x_o) = b - f(x_o)$.[3] Liquidity providers (LPs) who add liquidity proportional to the AMM's current state $h(x)$ must also provide their share of the backing collateral b.[3]

This collateral mechanism differs significantly from traditional margin systems. Regulation T margin typically requires a fixed percentage (e.g., 50%) of the purchase price for securities.[55] Futures markets use initial and maintenance margins based on expected price volatility over a short period, allowing substantial leverage.[53] Portfolio margin systems, available to sophisticated investors, calculate requirements based on the simulated risk of the *entire portfolio* under various market stress scenarios, allowing for netting of risks across positions.[55] OTC derivatives often involve bilaterally negotiated collateral agreements (or sometimes none), which proved inadequate in crises like the Lehman Brothers failure, leading to significant counterparty risk concerns.[29]

The distribution market collateral rule represents a form of *full collateralization against the worst-case outcome for that specific trade*. This provides strong solvency guarantees for the AMM against individual trades but might be capital-intensive for traders taking highly skewed or directional bets, potentially limiting leverage compared to futures or portfolio margin. However, it directly prices the downside risk embedded in the specific shape of the traded distribution function $\Delta f(x)$. This contrasts with portfolio margin's aggregate risk view or the standardized rules of Reg T/futures margin. Blockchain technology facilitates the implementation of these

collateral rules, locking collateral within smart contracts and automating margin calls or liquidations if necessary, potentially using tokenized forms of collateral beyond cash.[111]

A notable feature arises from this collateralization approach: it directly ties the capital required to the specific distributional bet being made. Unlike standardized margin requirements or even portfolio-level risk models, the collateral here is precisely the amount needed to cover the maximum loss defined by the payoff function $g(x) - f(x)$ across all possible states x. This offers a potentially more granular and economically meaningful measure of risk for the specific position being taken, though its capital efficiency relative to systems allowing netting and leverage depends heavily on the nature of the trade and the overall portfolio context.

3. Replication and Enhancement of Existing Financial Functions

A crucial test for any new financial primitive is its ability to replicate and potentially improve upon the functions of existing instruments. This section analyzes the capacity of distribution markets, underpinned by CFMM or MSR mechanisms, to replicate the payoffs and risk profiles of standard derivatives and to offer superior means for market expression and hedging compared to traditional proxy methods.

3.1. Derivatives Equivalence: Replicating Payoffs and Risks

The theoretical equivalence between CFMMs and cost-function prediction markets [14] provides a foundation for replicating traditional derivative payoffs within a distribution market framework. By constructing portfolios of outcome-specific securities (in a discrete setting) or by shaping the continuous outcome function $f(x)$, traders can theoretically match the payoff profiles of instruments like options and futures.

3.1.1. Theoretical Framework

The core idea is to represent the derivative's payoff at maturity as a function of the underlying variable's final value, $Payoff(x_0)$. In a distribution market for that underlying variable, a trader aims to construct a position $f(x)$ such that $f(x_0) = Payoff(x_0)$ for all relevant outcomes x_0. The cost of establishing this position $f(x)$ is determined by the AMM's cost function or invariant (e.g., LMSR cost [92], QMSR cost [88], or the L2-norm based cost in the Paradigm model [3]).

3.1.2. Options Replication (Calls, Puts, Spreads)

Standard options have non-linear, "kinked" payoff profiles, such as $max(S\_T - K, 0)$ for a European call option, where S_T is the underlying price at expiry and K is the strike

price. Replicating this in a distribution market involves constructing a position function *f(S_T)* that mimics this shape.

- Mathematical Construction: This can be achieved by combining positions across different outcome ranges. For instance, approximating a call option payoff involves taking long positions in outcomes above the strike K and potentially short positions (or zero positions) below K. A common technique in options markets is to use spreads. A call spread (long call at K_1, short call at K_2) has a bounded payoff. Similarly, combinations of interval securities in a distribution market can approximate option payoffs. The "condor spread" example, involving four interval securities, illustrates how combinations can create specific payoff shapes 15:
  *f(S) ≈ c **
  where 1_{condition} is an indicator function paying $1 if the condition is met, c is a scaling factor (like shares), and $K_1 < K_2 < K_3 < K_4$ are boundary points. By choosing appropriate boundaries and weights c, one can approximate the slope and curvature of standard option payoffs.15 The accuracy of this replication depends on the granularity and liquidity of the available intervals or the flexibility in shaping the continuous function f(x).15
- **Approximation of Greeks:** The sensitivities of the replicating position *f(x)* to changes in market parameters correspond to option Greeks [113]:
  - **Delta (Δ):** Measures the change in the position's value for a small change in the underlying's expected value (mean of the distribution). Mathematically, it relates to the derivative of the expected payoff *E[f(x)]* with respect to the mean of the distribution. In the functional representation, it's linked to the slope of *f(x)* around the current expected value.
  - **Gamma (Γ):** Measures the rate of change of Delta. It corresponds to the curvature (second derivative) of the position function *f(x)*.[114] Distribution markets allow direct construction of gamma profiles by shaping *f(x)* to be convex or concave in specific regions.[116] This contrasts with standard options where gamma is highest near the money and decays away from it.[114]
  - **Vega (ν):** Measures sensitivity to changes in implied volatility, which in a distribution market context translates to sensitivity to changes in the *spread* or *variance* of the market's implied PDF represented by *f(x)*. Trading distributions allows direct expression of views on the distribution's width, offering a more direct Vega exposure than standard options.[113]
  - **Theta (Θ):** Represents the time decay of the position's value as the resolution date approaches. This is influenced by how the market updates the distribution *f(x)* over time and the decreasing uncertainty.[113]
  - **Rho (ρ):** Sensitivity to changes in the risk-free interest rate, affecting the

discounting of future payoffs.[113]

The ability to directly shape the payoff function *f(x)* in a distribution market presents a potentially significant advantage over traditional options portfolios for managing complex risk exposures. Replicating specific Greek profiles, such as maintaining constant gamma exposure or targeting vega sensitivity in particular outcome ranges, often necessitates dynamic hedging or the construction of complex and potentially costly static portfolios using standard options. In theory, a distribution market allows a trader to encode a desired Greek profile directly into the shape of their position function *f(x)*. For example, a convex *f(x)* yields positive gamma. A function *f(x)* whose value increases significantly as the implied distribution widens (while keeping the mean constant) would have positive Vega. Achieving these profiles through a single, static position in the distribution market could be more capital-efficient and operationally simpler than managing a dynamic portfolio of standard options. However, the practical feasibility depends heavily on the market's liquidity across different functional shapes and the accuracy of the market's pricing mechanism for these complex positions.

3.1.3. Futures/Forwards Replication

Futures and forwards contracts have linear payoffs, e.g., $S_T - K$, where K is the futures price. Replicating this requires constructing a position $f(S_T)$ such that $f(S_T) = S_T - K$. This involves taking appropriately weighted positions across the entire distribution such that the expected payoff aligns with the linear profile and the expected value matches the forward price implied by the market distribution *f(x)*. This is generally simpler than replicating options due to the linearity of the payoff.

3.1.4. Swaps Replication

Swaps involve exchanging cash flows based on the future path or value of an underlying variable. A variance swap, for example, involves exchanging a fixed variance rate (variance strike) for the realized variance of an asset over a period.[35] Replicating such path-dependent or moment-dependent payoffs in a distribution market is conceptually linked to the novel applications discussed in Section 5. For a variance swap, one could envision a distribution market where the outcome variable is the *realized variance itself*, calculated according to a predefined methodology. A position *f(variance)* would then replicate the swap payoff if *f(realized_variance) = N * (realized_variance - K_{var})*, where *N* is the notional and *K_{var}* is the variance strike. Similarly, interest rate swaps could potentially be replicated by

trading distributions of future interest rates.

3.1.5. Comparative Analysis

Comparing distribution markets with standard derivatives for replication reveals trade-offs:

- **Capital Efficiency:** Distribution markets based on the Paradigm model require full collateralization against the maximum potential loss for a given trade ($-\min_x(g(x) - f(x))$).[3] This ensures solvency for individual trades but can be capital-intensive compared to the margining systems used for futures and options, which allow significant leverage.[53] Futures typically require low initial margin (3-12%) [120], while portfolio margin allows netting of risks across complex option positions, often resulting in lower requirements than simpler rules.[55] Therefore, for directional or unhedged bets, distribution markets might be less capital-efficient. However, for perfectly hedged portfolios *within* the distribution market (e.g., replicating a risk-free payoff), the mechanism might implicitly recognize the zero risk and require minimal net collateral, potentially offering efficiency gains over systems that require gross margining. The specific MSR used also impacts capital; LMSR has unbounded potential loss for the market maker (though bounded by parameter *b*), while QMSR can be designed with bounded loss.[88]
- **Basis Risk:** Basis risk arises when the hedging instrument does not perfectly correlate with the underlying exposure being hedged.[122] A key potential advantage of distribution markets is the reduction of basis risk when hedging complex events.[123] If the market directly trades the distribution of the variable of interest (e.g., climate outcome, technological adoption rate), it eliminates the need for imperfect financial proxies (like VIX for geopolitics [5] or equities for specific tech impacts [127]). However, new forms of basis risk emerge: *oracle risk* (the risk that the oracle's reported outcome x_0 differs from the true economic outcome relevant to the hedger) [3] and *model risk* (the risk that the specific distribution market mechanism or assumed distribution family misrepresents the true underlying process).
- **Usability:** Standardized, exchange-traded derivatives (futures, listed options) offer high usability due to liquidity, clear rules, and established infrastructure.[28] OTC derivatives provide customization but involve negotiation, counterparty risk, and opacity.[28] Distribution markets, requiring users to think in terms of probability distributions and functional positions, present a significantly higher usability challenge.[67] Constructing and managing replicating portfolios, especially for complex payoffs or Greek profiles, demands considerable quantitative expertise,

likely limiting participation compared to standard instruments.

Table 1: Comparative Analysis: Distribution Markets vs. Standard Derivatives

Feature	Distribution Markets (Paradigm Model)	Listed Options/Futures	OTC Derivatives
Payoff Replication	Direct shaping of payoff function *f(x)*; potentially precise	Standardized payoffs; replication of complex payoffs needs portfolios	Highly customizable payoffs possible
Greek Exposure	Direct construction via shaping *f(x)* (e.g., convexity for Gamma)	Indirect exposure; complex profiles require portfolios/dynamics	Customizable, but often opaque
Capital Efficiency	Full collateralization of max loss per trade; potentially low leverage	High leverage via margin (esp. Futures); Portfolio Margin allows netting	Varies; often bilateral collateral, potentially under-collateralized [105]
Basis Risk	Reduced proxy risk if direct; Oracle/Model risk introduced	Basis risk exists if underlying/index mismatches exposure	Basis risk depends on contract specificity vs. exposure
Transparency	High (on-chain logic, positions, settlement) [31]	High (exchange prices, volumes) [28]	Low (bilateral, opaque pricing/positions) [28]
Counterparty Risk	Eliminated/Reduced via smart contracts/collateral [31]	Mitigated by Central Clearing Party (CCP) [28]	Significant bilateral risk; major crisis factor [30]
Standardization	Low (arbitrary functions *f(x)* possible)	High (standardized contracts) [28]	Low (bespoke contracts) [28]
Usability/Complexity	High (requires understanding	Medium (options can be complex)	High (negotiation, legal complexity)

	distributions, functions) [67]		

3.2. Market Expression and Hedging Complex Events

A significant potential application of distribution markets lies in providing more direct and efficient tools for expressing views on, or hedging against, complex, often non-financial, events compared to relying on traditional financial market proxies.

3.2.1. Limitations of Proxy Hedging

Investors and firms often seek to manage exposures to events like geopolitical instability, disruptive technological shifts, or climate change impacts. Lacking direct markets for these events, they frequently resort to using existing financial instruments as proxies.[123] For example:

- **Geopolitical Risk:** Traders might use volatility indices like the VIX, defense stocks, oil futures, or currencies as proxies for geopolitical tension.[5] However, the correlation is often weak and unreliable. The VIX, for instance, measures expected S&P 500 volatility, which correlates poorly with geopolitical risk indices; major market routs have occurred during periods of geopolitical calm, and vice versa.[5] Geopolitical events impact markets primarily through their economic consequences (damaging confidence, disrupting supply chains), not just through rhetoric, making financial proxies indirect and noisy indicators.[5]
- **Technological Breakthroughs:** Expressing a view on the impact or timing of a technology like AI might involve investing in specific tech stocks or ETFs.[127] However, stock prices are influenced by myriad factors beyond the specific technological development (competition, regulation, overall market sentiment).[127] Using broad market indices as proxies for wealth is also known to be problematic in testing financial models.[128] Furthermore, the impact can be complex and cross-sectoral (e.g., AI impacting energy demand), making simple equity proxies inadequate.[134] Private equity might offer exposure but involves illiquidity and different risk profiles.[136]
- **Climate Change Risk:** Hedging climate risk might involve trading commodity futures (e.g., carbon credits, energy futures), investing in renewable energy stocks, shorting fossil fuel companies, or using ESG scores.[137] However, commodity futures can be inefficient hedges due to factors like storage costs, weather patterns unrelated to long-term climate change, and policy uncertainty affecting specific commodities differently.[137] ESG scores lack standardization and may not accurately capture climate risk exposure.[137] The long-term, systemic nature of climate risk makes standard futures or insurance contracts difficult to

implement due to counterparty risk over decades.[140]

The fundamental problem with proxy hedging is **basis risk** – the imperfect correlation between the proxy instrument and the actual exposure being hedged.[122] This mismatch can lead to ineffective hedges or even losses. Additionally, financial proxies aggregate information about numerous factors, diluting the signal related to the specific event of interest and making accurate information aggregation difficult.[17] Proxies offer blunt exposure, lacking the granularity to hedge specific facets of a complex event.

3.2.2. Distribution Markets as Direct Hedging/Expression Tools

Distribution markets offer a compelling alternative by allowing participants to trade *directly* on the probability distribution of the complex event's outcome variable. Instead of trading VIX futures to hedge election uncertainty, one could trade on the distribution of the vote share difference. Instead of buying tech stocks to bet on AI progress, one could trade on the distribution of timelines for achieving specific AI milestones. Instead of using carbon futures to hedge climate transition risk, one could trade on the distribution of global average temperature increase by 2050 or the distribution of economic damages from climate change.

This direct approach offers several theoretical advantages:

- **Theoretical Purity and Reduced Basis Risk:** By targeting the event distribution itself, these markets eliminate the basis risk associated with using correlated-but-distinct financial proxies.[122] The hedge is directly linked to the variable of concern. The basis risk shifts from proxy correlation to the accuracy and reliability of the market's outcome resolution (oracle risk) and the appropriateness of the market model.
- **Enhanced Information Aggregation:** Prediction markets are explicitly designed for information aggregation.[66] A market focused solely on the distribution of a specific complex event is theoretically better positioned to aggregate dispersed knowledge, signals, and expert opinions about *that event* compared to a broad financial market influenced by countless other factors.[75] The ability to trade the entire distribution allows aggregation beyond simple point forecasts or binary outcomes, capturing nuances about uncertainty, skewness, and potential tail events.[149] This aligns with the "wisdom of the crowd" principle applied to density estimation.[39]
- **Risk Management Precision:** Trading the distribution allows for highly specific risk management. A firm concerned about extreme climate outcomes could specifically buy protection in the tail of the temperature distribution market. An

investor wanting to bet on rapid AI development could take positions reflecting a distribution heavily skewed towards early dates. This precision is difficult, if not impossible, to achieve using broad market proxies.

While theoretically appealing, the practical success of distribution markets for hedging complex events faces significant hurdles. These markets need to attract sufficient liquidity, particularly from informed participants, to ensure efficient price discovery and meaningful aggregation. Low liquidity can render prices uninformative or easily manipulable.[26] Furthermore, the challenge of defining clear, unambiguous, and reliably resolvable outcome variables for complex, long-term events (like climate change or AGI development) is substantial. The oracle mechanism must be robust and trusted over potentially long horizons.[3] Therefore, the theoretical gain in precision and directness must be weighed against the practical difficulties in achieving sufficient market depth and ensuring credible outcome resolution. The ideal use cases might initially be for events with clearer definitions and shorter time horizons where oracle solutions are more feasible.

4. Potential for Market Displacement and Augmentation

Distribution markets, with their unique capabilities for expressing and trading probabilistic beliefs, possess the potential to not only complement but also displace or significantly augment segments of existing financial and betting markets currently characterized by inefficiencies or limitations. This section reviews specific market areas where distribution markets might offer superior alternatives.

4.1. Identifying Inefficiencies in Existing Markets

Several areas within the current financial and betting landscape exhibit characteristics that make them potential candidates for disruption or enhancement by distribution markets:

4.1.1. Bespoke OTC Derivatives

Over-the-counter (OTC) derivatives markets facilitate the creation of customized contracts tailored to specific hedging or speculative needs.[28] However, this customization comes at a cost:

- **Opacity:** Trades are negotiated bilaterally, often lacking price transparency. Market participants may not know the prevailing "fair" price or the extent of others' positions.[28] This opacity hinders efficient price discovery and makes systemic risk assessment difficult for regulators.[105]
- **Counterparty Risk:** Each party bears the risk that the other will default on its

obligations.[28] This risk was a central factor in the 2008 financial crisis, particularly highlighted by the failures or near-failures of institutions like Lehman Brothers and AIG, which had massive OTC derivative exposures.[30] Collateral requirements are often insufficient or inconsistently applied.[29]

- **Illiquidity:** Bespoke contracts are inherently less liquid than standardized, exchange-traded instruments, making it potentially difficult or costly to exit positions before maturity.[28]
- **Intermediation Costs:** Trading typically involves dealer intermediaries, adding transaction costs and complexity.

While reforms post-2008 mandated central clearing (via Central Counterparties or CCPs) for many standardized OTC derivatives to mitigate counterparty risk and improve transparency [103], a significant portion, particularly highly customized or complex contracts, remains uncleared.[29] Furthermore, CCPs themselves can concentrate risk, potentially becoming new systemic points of failure.[107]

4.1.2. Structured Products

Structured products (like structured notes, ETNs) combine traditional debt instruments with derivatives (often options) to offer customized payoff profiles, such as principal protection or enhanced yield, linked to an underlying asset or index.[7] While popular, especially in low-interest-rate environments [22], they suffer from several drawbacks:

- **Complexity:** Their payoff structures can be highly complex, involving barriers, caps, and path-dependencies that are difficult for investors, particularly retail investors, to fully understand.[7] This raises suitability concerns.[158]
- **Opacity:** Pricing is often opaque, with embedded fees and issuer margins that are not explicitly disclosed, making it hard to assess true value or compare products.[7]
- **Illiquidity:** A secondary market rarely exists, making them primarily buy-and-hold investments. Selling before maturity often involves significant discounts.[7] While ETNs offer exchange trading, they are still debt instruments subject to issuer risk.[7]
- **Issuer Credit Risk:** Structured products are typically unsecured debt obligations of the issuing financial institution. Investors are exposed to the issuer's creditworthiness; default can lead to loss of principal.[7]
- **Mispricing:** Studies suggest structured products, including Credit Linked Notes (CLNs), are often overpriced in the primary market.[168] Complexity tends to exacerbate mispricing.[168] While the 2008 crisis led to some reduction in overpricing due to increased awareness and regulation, challenges remain.[168] The

crisis also highlighted the fragility of structured finance ratings and the potential for fire sales in illiquid markets.[20]

4.1.3. Parimutuel Betting Pools

Parimutuel systems, common in horse racing and some lotteries, pool all wagers, deduct a "takeout" for the operator, and distribute the remaining pool proportionally among those who bet on the winning outcome.[23] Key limitations include:

- **Lack of Continuous Pricing:** Odds are not fixed until betting closes, meaning participants place bets without knowing the final payoff structure.[8] This contrasts with fixed-odds betting or financial markets with continuous price discovery.
- **Information Aggregation Inefficiency:** While parimutuel odds reflect collective betting patterns, they are often considered less efficient at aggregating information than prediction markets or fixed-odds markets.[26] The lack of continuous pricing and the inability to trade out of positions hinders the dynamic incorporation of new information.
- **Favorite-Longshot Bias:** A well-documented anomaly where low-probability outcomes (longshots) are over-bet relative to their true chances, and high-probability outcomes (favorites) are under-bet, leading to systematically lower returns on longshot bets.[23]
- **Manipulation Potential:** While field experiments suggest manipulation via large temporary bets might be difficult due to market corrections [24], the structure can still be vulnerable, especially in thinner pools or where outcomes can be influenced.[179]

4.2. Distribution Markets as Superior Alternatives

Blockchain-based distribution markets, utilizing AMM/MSR mechanisms, offer potential solutions to many of the inefficiencies identified above:

- **Transparency:** The underlying AMM logic (the invariant or cost function) is typically open-source, and all trades and pool states are recorded on an immutable public ledger.[31] This provides unprecedented transparency compared to opaque OTC deals or structured product pricing. Settlement is automated and verifiable.[181]
- **Expressiveness:** The ability to trade arbitrary distributions *f(x)* allows for the creation of highly customized payoff profiles directly within the market mechanism.[3] This could replicate the tailoring of bespoke OTC derivatives or structured products but within a more standardized and transparent framework.
- **Continuous Price Discovery:** AMMs continuously adjust implied probabilities (the shape of *f(x)*) based on trading activity.[3] This provides real-time price signals,

unlike the static odds in parimutuel pools determined only at the close of betting.[23] Prediction markets generally offer more dynamic pricing than traditional betting.[74]

- **Capital Efficiency:** While full collateralization [3] might limit leverage on directional bets, the internal netting within the distribution framework and collateral tied directly to the traded risk profile could be more efficient than opaque bilateral collateral arrangements or potentially overpriced structured products. Reduced intermediation costs on DEX platforms could also enhance efficiency.[63]
- **Reduced Counterparty Risk:** By using smart contracts for trade execution, settlement, and collateral management on a blockchain, distribution markets can virtually eliminate bilateral counterparty default risk.[31] This is a major advantage over OTC markets [30] and removes the issuer credit risk inherent in structured products.[7] Risk is shifted to smart contract security and oracle reliability.
- **Accessibility:** Decentralized platforms can potentially offer broader access to sophisticated hedging and speculative tools compared to the institutional focus of OTC markets or the distribution channels for structured products.[22] However, the inherent complexity remains a barrier.[67]

4.3. Specific Examples of Displacement/Augmentation

Based on these advantages, distribution markets could target specific needs currently met by less efficient structures:

1. **Custom Hedging for Corporates:** Instead of negotiating complex, opaque OTC forwards or swaps for non-standard commodity grades, locations, or risk factors (e.g., hedging specific weather patterns affecting crop yield), a corporate could participate in a distribution market directly focused on the distribution of that specific variable. *Advantage:* Transparency, potentially lower costs, reduced counterparty risk.
2. **Replacing Structured Notes:** An investor seeking principal protection with participation in equity upside could, instead of buying a structured note, construct a similar payoff profile within a distribution market on the relevant equity index. This could involve buying the "tail" of the distribution (for upside) and using the premium generated from selling other parts of the distribution (or adding capital) to ensure the downside payoff is floored at the initial investment. *Advantage:* Transparency on costs/pricing, elimination of issuer credit risk, potentially greater flexibility.
3. **Sophisticated Event/Political Risk Trading:** Replace binary outcome prediction markets or inefficient proxy hedges with distribution markets on continuous variables related to the event (e.g., distribution of election margin, distribution of

policy impact metrics). *Advantage:* Greater expressiveness, more nuanced information aggregation, direct hedging of specific outcome ranges.[2]

4. **Enhanced Sports/Event Wagering:** Augment or replace parimutuel pools or fixed-odds bookmakers with distribution markets on continuous game statistics (e.g., distribution of point differentials, player performance metrics). *Advantage:* Continuous price discovery, ability to trade volatility or skewness of outcomes, potentially fairer odds due to reduced operator take and direct peer-to-peer trading.[26]

Table 2: Potential Displacement/Augmentation Opportunities

Existing Market/Product	Key Inefficiencies	Potential Distribution Market Advantage	Example Application
Bespoke OTC Derivatives	Opacity [103], Counterparty Risk [29], Illiquidity [28], High Intermediation Costs	Transparency [97], Reduced Counterparty Risk [31], Continuous Pricing, Potential for Lower Costs	Hedging non-standard commodity basis risk (e.g., specific crop yield distribution)
Structured Products	Complexity [7], Pricing Opacity/Mispricing [7], Illiquidity [159], Issuer Credit Risk [7]	Transparency [97], No Issuer Risk, Customizable Payoffs, Potential for Better Pricing	Replicating principal-protected equity participation note via trading index distribution
Parimutuel Betting Pools	No Continuous Pricing [23], Favorite-Longshot Bias [23], Lower Information Efficiency [26], High Takeout Rates	Continuous Pricing/Odds, Direct P2P Trading, Greater Expressiveness, Potentially Better Aggregation	Trading the distribution of point spreads or player performance metrics in sports
Proxy Hedging (Complex Events)	Basis Risk [122], Imperfect Correlation [5], Lack of Specificity, Noisy Information	Direct Exposure to Event Variable, Reduced Basis Risk (to Oracle/Model Risk), Precise	Hedging climate risk via market on distribution of future temperature anomalies; Hedging

	Aggregation [17]	Hedging, Focused Aggregation	tech disruption via market on adoption rate distribution

5. Novel Market Applications Enabled by Distribution Trading

Beyond replicating or improving existing financial functions, the ability to trade arbitrary probability distributions via mechanisms like functional CFMMs or generalized MSRs unlocks the potential for entirely new types of markets and financial expressions. These novel applications could address previously unhedgeable risks or facilitate information aggregation at an unprecedented level of detail.

5.1. Beyond Existing Paradigms

Current financial markets primarily allow trading based on expected future price levels (futures), volatility (options), or binary event outcomes (prediction markets). The capacity to trade the *entire shape* of a probability distribution—its variance, skewness, kurtosis, modality, tail dependencies, etc.—represents a fundamental expansion of the financial toolkit. This section proposes and elaborates on several distinct, novel market formulations made possible by this capability.

5.2. Proposed Novel Application 1: Higher-Moment Markets

- **Concept:** The creation of markets where the traded asset's payoff is directly determined by a higher statistical moment of an underlying variable's realized distribution over a specified period. While variance swaps exist [35], distribution markets could generalize this to other moments like skewness and kurtosis, offering purer exposure than complex option portfolios.[36]
- **Mechanics:**
    1. **Define Underlying Variable:** e.g., daily returns of the S&P 500 index.
    2. **Define Measurement Period:** e.g., the next calendar month.
    3. **Define Moment Calculation:** Specify the precise formula for calculating the realized moment (e.g., sample variance, sample skewness, sample excess kurtosis) from the underlying variable's data over the measurement period. This calculation methodology acts as the market's resolution source.
    4. **Market Operation:** Participants trade a distribution function *f(m)*, where *m* is the potential value of the realized moment (e.g., *f(variance)*, *f(skewness)*, *f(kurtosis)*). The AMM (e.g., Paradigm's L2-norm CFMM) facilitates trading based on its invariant.
    5. **Settlement:** At the end of the measurement period, the realized moment m_o is calculated according to the predefined formula. An oracle reports m_o to the

smart contract. Traders holding position *f(m)* receive a payoff of $f(m_0)$.

- **Rationale/Value:**
  - *Direct Exposure:* Provides pure-play exposure to specific higher moments. Variance markets allow direct volatility trading/hedging.[35] Skewness markets allow direct trading on asymmetry risk (e.g., crash risk premium).[40] Kurtosis markets allow trading on tail risk or the likelihood of extreme events ("fat tails").[188]
  - *Efficiency:* Potentially more transparent and capital-efficient than replicating these exposures using strips of options (for variance swaps) or complex option strategies like risk reversals (for skewness) or butterflies/condors (for kurtosis).[42]
  - *Information Aggregation:* Creates a direct market signal for the expected level and uncertainty around future realized variance, skewness, or kurtosis.
- **User Base:** Quantitative hedge funds executing statistical arbitrage or volatility/tail risk strategies, asset managers hedging portfolio exposures to higher moments, insurance companies managing liabilities sensitive to extreme events (e.g., variable annuities).[119]

A key consideration for higher-moment markets is the precise definition and calculation of the realized moment. This definition acts as the oracle, and any ambiguity or potential for manipulation in the calculation method could undermine the market's integrity. For example, should variance be calculated from daily closing prices, intraday data, or high-frequency data? The choice impacts the resulting value and the nature of the risk being traded. Despite this challenge, the ability to isolate and trade these fundamental aspects of distributional shape offers a significant potential expansion of risk management capabilities. It could democratize access to risk factors that were previously the domain of sophisticated derivatives desks, provided the oracle problem can be reliably solved.

5.3. Proposed Novel Application 2: Complex Contingent Claims on Distribution Shape

- **Concept:** Designing derivative contracts whose payoffs are contingent not just on the final realized outcome x_0, but on the *shape* or specific *features* of the market's implied probability distribution *f(x)* at the moment of expiration or resolution. This allows for "meta-bets" on the market's consensus itself.
- **Mechanics:**
  1. **Define Underlying Distribution Market:** A standard distribution market on an outcome *x*, resulting in a final implied distribution *f_{final}(x)* at time *T*.

    2. **Define Payoff Function:** The payoff depends on *f_{final}(x)* and potentially the realized outcome x_0. Examples:
        - *Modality Option:* Pays $1 if *f_{final}(x)* is multimodal (e.g., has more than one distinct peak), $0 otherwise. This bets on market disagreement or the emergence of distinct scenarios.
        - *Consensus Strength Option:* Pays $1 if the variance (or entropy) of *f_{final}(x)* is below a certain threshold, $0 otherwise. This bets on a strong market consensus forming.
        - *Tail Disagreement Option:* Pays $1 if the ratio of the probability mass in the right tail versus the left tail of *f_{final}(x)* (e.g., $P(x > \mu+2\sigma) / P(x < \mu-2\sigma)$) exceeds a threshold. This bets on asymmetric tail risk perception.
        - *Surprise Index:* Pays *1 / f_{final}(x_0)* if outcome x_0 occurs. This payoff is large if the realized outcome was deemed very unlikely by the final market distribution, rewarding those who bet against a strong consensus that turned out wrong. (Requires careful normalization/bounding).
        - *Distribution Distance Claim:* Pays off based on a distance metric (e.g., KL divergence, Wasserstein distance) between *f_{final}(x)* and a pre-defined benchmark distribution *g(x)*. This allows betting on how far the market consensus will deviate from a baseline forecast.
    3. **Market Operation:** These complex claims could be traded in a separate, standard binary options market, or potentially integrated into the distribution market framework itself if the payoff can be represented appropriately.
    4. **Settlement:** Requires an oracle to report not only x_0 but also the final state *f_{final}(x)* of the underlying distribution market. The payoff is then calculated based on the defined function.
- **Rationale/Value:**
    - *Trading Consensus:* Allows direct speculation on the properties of market beliefs themselves (e.g., degree of consensus, perceived tail risks, presence of multiple scenarios).
    - *Hedging Model/Belief Risk:* Enables hedging against the risk that the market consensus (*f_{final}(x)*) proves to be fundamentally wrong or unstable.
    - *New Information Elicitation:* Creates incentives to forecast not just the outcome, but the *market's perception* of the outcome distribution.
- **User Base:** Highly sophisticated quantitative traders, market microstructure researchers, potentially market supervisors interested in monitoring consensus

dynamics and stability.

These markets delve into second-order prediction problems – forecasting the forecast. Their feasibility relies heavily on the ability to reliably capture and input the final distribution shape *f_{final}(x)* into the settlement logic, adding another layer of oracle complexity.

5.4. Proposed Novel Application 3: Model-Based Hedging Markets

- **Concept:** Creating distribution markets where the underlying variable is not a real-world outcome, but the *output* of a specific, complex quantitative model run at a future date. This allows users to directly hedge their exposure to the uncertainty or potential inaccuracies of the model itself.[38] Many critical decisions in finance, policy, and science rely on such models, yet hedging the risk associated with the model's output is often difficult.[9]
- **Mechanics:**
    1. **Specify Model & Run:** Define the exact model (e.g., a specific climate model ensemble like CMIP7, a particular epidemiological model like SEIR with defined parameters, a bank's internal VaR model), the inputs/assumptions for a specific future run, and the specific output variable of interest (e.g., projected global temperature anomaly for 2050, peak hospitalizations forecasted, 1-day 99% VaR).
    2. **Market Definition:** The "event" is the execution of this specific model run at a future date *T_{run}*. The "outcome" is the value of the specified output variable from that run.
    3. **Market Operation:** Participants trade the distribution function *f(model_output)* representing their beliefs about the likely output of the future model run.
    4. **Settlement:** At *T_{run}*, the model is executed as specified. An oracle reports the resulting output value m_0 to the market. Traders holding $f(m)$ receive payoff $f(m_0)$.
- **Rationale/Value:**
    - *Direct Model Risk Hedging:* Allows entities whose decisions or financial performance depend on a model's output to hedge the risk that the model produces an unfavorable or unexpected result. For example, a bank required to hold capital based on its VaR model [45] could hedge against the model producing a very high VaR figure in the future. Policymakers relying on climate model projections [44] could hedge against projections indicating unexpectedly severe outcomes requiring costly interventions.
    - *Model Comparison & Validation:* Running parallel markets on the outputs of

different competing models could provide a market-based assessment of their relative credibility or expected divergence.
    - *Pricing Model Uncertainty:* Creates a market price for the uncertainty inherent in specific, widely used models.
- **User Base:** Financial institutions managing model risk, insurance companies, energy companies, government agencies relying on climate or epidemiological forecasts [38], regulators, quantitative researchers, model developers.

This application effectively transforms *model uncertainty* into a tradable asset class. The primary challenge lies in precisely defining the model, its inputs, and the execution environment to ensure unambiguous resolution. It isolates model risk from real-world outcome risk, providing a unique hedging tool for sophisticated users heavily reliant on specific quantitative forecasts.

5.5. Proposed Novel Application 4: Markets for Subjective Distribution Elicitation

- **Concept:** Leveraging the mathematical framework of distribution markets (specifically MSRs or equivalent CFMMs) to elicit *full subjective probability distributions* from experts or crowds, particularly for events where objective ground truth is unavailable, ambiguous, or significantly delayed.[33] This goes beyond eliciting point forecasts or simple probabilities.
- **Mechanics:**
    1. **Define Elicitation Target:** Specify the variable for which a subjective probability distribution is desired (e.g., expert's belief about the 5-year market share of a new technology, a geopolitical analyst's assessment of the probability distribution of conflict escalation levels).
    2. **Mechanism Design:** Employ an MSR framework (like LMSR or QMSR adapted for continuous distributions) or an equivalent CFMM. Since ground truth may be unavailable for scoring, incentives must rely on other principles:
        - *Peer Prediction:* Payoffs based on comparison to the reports of other participants, rewarding reports that are "surprisingly common".[33]
        - *Proxy Scoring:* Score based on correlation with a related, verifiable outcome.
        - *Information Markets:* Structure the market such that participants trade based on their full distribution, with profits derived from improving the market consensus towards a more accurate representation of collective (subjective) knowledge, even if ultimate truth is unknown. This leverages the information aggregation properties inherent in MSR/CFMM mechanisms.[14]
    3. **Reporting Format:** Participants might report parameters of a chosen

distribution family (e.g., mean, variance, skewness of a skewed normal) or provide non-parametric inputs (e.g., quantiles, histograms) that define their subjective PDF. Recent work explores eliciting natural language rationales alongside beliefs.[208]

- **Rationale/Value:**
  - *Richer Information:* Captures the full extent of an expert's or crowd's belief, including their assessment of uncertainty, asymmetry, and tail risks, which are lost in point forecasts.[149]
  - *Quantifying Subjectivity:* Provides a structured, incentivized way to quantify and aggregate subjective judgments for complex forecasting tasks.
  - *Wisdom of Crowds for Densities:* Extends the "wisdom of the crowd" principle from point estimation to full density estimation.[39]
- **User Base:** Intelligence analysis, corporate strategic planning, technology forecasting, policy analysis, academic research requiring subjective probability assessments.

The main challenge here is designing effective incentive mechanisms when direct outcome-based scoring is not possible. Peer prediction methods can be complex and sensitive to collusion or strategic reporting. However, the underlying MSR/CFMM structure, designed to reward improvements in the collective forecast, may provide a robust basis even without ground truth resolution.

5.6. Proposed Novel Application 5: Conditional Distribution Markets

- **Concept:** Creating markets specifically designed for trading *conditional* probability distributions, $f(y|X)$, representing the distribution of an outcome Y given that another event X occurs or another variable X falls within a certain range.
- **Mechanics:**
  1. **Define Events/Variables:** Specify the target variable Y and the conditioning event/variable X.
  2. **Market Structure:** Design an AMM or MSR where trades explicitly represent positions on the conditional distribution $f(y|X)$. This is more complex than standard distribution markets.
     - *Approach 1 (Contingent Activation):* Run a distribution market for Y, but payoffs are only made if event X occurs (as determined by an oracle). Trades implicitly reflect $f(y|X)$.
     - *Approach 2 (Explicit Conditional Contracts):* Define outcome tokens or functional positions that explicitly represent claims on $f(y|X)$. For example, a contract pays $f(y_0|X)$ if X occurs and $Y=y_0$. This requires a more

sophisticated AMM design. Hanson's work on MSRs for conditional probabilities provides a starting point.[86]
3. **Settlement:** Requires oracles for both *X* and *Y*. If *X* does not occur, the market might resolve to zero or return collateral. If *X* occurs, settlement proceeds based on the realized value y_o and the positions taken on $f(y|X)$.

- **Rationale/Value:**
  - *Direct Trading of Dependencies:* Allows market participants to directly express views on and trade the relationship *between* variables, rather than just their marginal distributions.
  - *Causal Inference Support:* Market prices for conditional distributions could provide valuable inputs for causal analysis and understanding impact pathways.
  - *Enhanced Scenario Analysis:* Enables more sophisticated risk management by allowing hedging against outcomes conditional on specific scenarios (*X*) materializing.
- **User Base:** Econometricians, causal inference researchers, policy analysts evaluating intervention impacts, risk managers performing complex scenario modeling.

Conditional distribution markets represent a significant step up in complexity, both in mechanism design and user understanding. Defining the state space and handling the conditionality within the AMM/MSR framework requires careful theoretical development. However, the potential to directly trade and aggregate information about dependencies makes this a potentially high-impact area for future research.

Table 3: Proposed Novel Applications

Application Name	Core Concept	Key Mechanics	Unique Value Proposition	Potential User Base
Higher-Moment Markets	Trading directly on the future realized variance, skewness, or kurtosis of an underlying variable's distribution	Distribution market where outcome is the calculated moment m; payoff $f(m_o)$ based on realized moment m_o	Direct, pure-play exposure to volatility/tail/extremity risk; potentially more efficient than option portfolios [35]	Quant funds, risk managers, insurers [119]

Complex Contingent Claims	Derivatives whose payoff depends on the *shape* of the market's implied distribution *f(x)* at expiration	Payoff function depends on *f_{final}(x)* (e.g., modality, variance, distance to benchmark); requires oracle for *f_{final}(x)*	Enables meta-bets on market consensus, model uncertainty, specific distributional features (e.g., multimodality) [118]	Sophisticated quants, market researchers, regulators
Model-Based Hedging Markets	Trading the distribution of a specific *model's output* at a future date	Distribution market where outcome is the output of a predefined model run; payoff *f(model_output)*	Direct hedging of model risk itself; model comparison; pricing model uncertainty [44]	Institutions using models (banks, insurers, gov't agencies), regulators, model developers [38]
Subjective Distribution Elicitation	Using market mechanisms to elicit full subjective probability distributions, especially without ground truth	MSR/CFMM framework adapted for distributions; incentives via peer prediction or other non-outcome methods [33]	Captures richer belief information (uncertainty, skew) than point forecasts; aggregates subjective expertise [153]	Intelligence analysis, corporate strategy, policy makers, researchers
Conditional Distribution Markets	Trading the probability distribution of *Y* conditional on *X*, *f(y | X)*	Market structure for conditional bets; payoffs contingent on *X* occurring, then resolved based on *Y*; complex AMM/MSR design [86]	Direct trading of dependencies; supports causal inference and scenario analysis; enhanced risk management	

6. Comparative Analysis of Intrinsic Market Properties

Beyond specific applications, the fundamental design of distribution markets based

on functional AMMs or MSRs leads to distinct characteristics regarding leverage, optionality, liquidity, price impact, and settlement compared to traditional market structures. Understanding these differences is crucial for assessing their potential advantages and disadvantages.

6.1. Leverage

Leverage, the ability to control a large nominal position with a smaller amount of capital, manifests differently in various market structures.

- **Manifestation in Distribution Markets:** The Paradigm model, with its requirement to fully collateralize the maximum potential loss for any given trade ($-min_x(g(x) - f(x))$) [3], appears to inherently limit leverage in the traditional sense. Unlike futures markets where a small initial margin controls a large notional contract value [53], or options where leverage is inherent in the low premium relative to potential underlying movement [120], the distribution market trader must post capital covering the worst possible outcome of their specific distributional bet. This design prioritizes solvency over leverage for individual trades. However, this does not mean leverage is entirely absent. A trader can construct a position function *f(x)* that offers extremely high payoffs for specific, low-probability outcomes (e.g., in the tails of the distribution), funded by small losses across more probable outcomes. While the *total capital at risk* is fully collateralized against the worst outcome, the *sensitivity* of the position's value to the occurrence of that specific low-probability outcome can be immense, creating a form of *implicit leverage* on particular distributional features or events. The leverage is not achieved by borrowing capital, but by shaping the payoff function itself. MSR-based markets, like LMSR, also have leverage characteristics tied to the liquidity parameter *b*; a smaller *b* means trades have a larger price impact, implying higher leverage for traders moving the price, but also potentially higher costs (loss) for the market maker.[89]
- **Comparison:**
  - *Traditional Margin (Reg T):* Fixed percentage requirement (e.g., 50%), relatively low leverage.[55]
  - *Portfolio Margin:* Risk-based calculation across the portfolio, allows netting, potentially higher leverage for hedged positions than Reg T.[55]
  - *Futures:* Low initial margin requirements (often 3-12%), enabling very high leverage.[53]
  - *Options:* Inherent leverage due to low premium relative to underlying exposure; leverage changes dynamically with price (Delta).[54]
  - *Distribution Markets (Paradigm):* Explicit leverage limited by full

collateralization of max loss. Implicit leverage achievable through payoff function shaping. Leverage in MSRs depends on liquidity parameter *b*.[89]

The full collateralization approach in the Paradigm model offers enhanced solvency at the cost of traditional leverage. The implicit leverage via payoff shaping, however, provides a powerful tool for expressing highly specific views, albeit requiring significant sophistication. MSR leverage dynamics depend on the specific rule and parameterization.[51]

6.2. Optionality and Convexity

Optionality refers to the non-linear payoff structure characteristic of options, where upside potential can be captured while downside risk is limited (for long positions). Convexity, mathematically related to the second derivative (Gamma for options), describes how the sensitivity (Delta) changes as the underlying price moves; positive convexity benefits holders in volatile markets.[116]

- **Inherent Optionality in Distribution Markets:** Trading distributions inherently allows for the creation of optionality. By constructing a position function $f(x)$ that is non-zero only above a certain threshold K and increases thereafter, a trader can replicate the payoff profile of a call option.[15] Similarly, a put-like payoff can be constructed. The ability to freely shape $f(x)$ means that virtually any payoff profile, including those with capped gains, specific barriers, or other exotic features often found in structured products [159], can theoretically be constructed directly within the distribution market framework.[57] This contrasts with needing to buy specific option contracts in traditional markets.
- **Convexity:** Long option positions naturally exhibit positive convexity (positive Gamma).[114] Distribution market positions *can* be constructed to have positive convexity by shaping the function $f(x)$ to be convex (i.e., its second derivative is positive). For example, a function $f(x) = c * max(x-K, 0)^2$ would exhibit positive Gamma. The MSR/CFMM mechanism itself, particularly the cost function, influences the feasibility and cost of achieving convexity. Both LMSR and QMSR have convex cost functions (or equivalently, concave potential functions), which is fundamental to their operation as markets.[49] The specific shape of this convexity (logarithmic vs. quadratic) affects the pricing of trades that introduce convexity into a trader's position $f(x)$. QMSR, with its quadratic cost, might map more naturally to replicating quadratic payoffs or constant Gamma profiles compared to LMSR.[49]
- **Trading Tails vs. Buying Options:** Buying deep out-of-the-money (OTM) options is a common strategy to gain exposure to tail events.[116] Distribution markets allow an alternative: directly taking a long position in the corresponding

tail region of the distribution function *f(x)*. This provides a more direct way to express a view on the probability mass in the tail, rather than relying on the indirect pricing of tail risk embedded in OTM option premiums (which are also affected by volatility, time decay, etc.). The relative cost and effectiveness depend on how the distribution market prices tail positions versus how the options market prices OTM options (often involving volatility skew/smile effects [210]).

In essence, distribution markets offer *generalized optionality* by allowing traders to sculpt arbitrary payoff functions *f(x)*, including those with convexity, directly through their trading activity. This provides potentially greater flexibility than assembling portfolios of standard options but requires sophisticated understanding and depends on the market's ability to price these complex functional shapes efficiently.

6.3. Liquidity Dynamics and Price Impact

Liquidity, the ease with which assets can be traded without significantly affecting their price, operates differently in AMM-based distribution markets compared to traditional Limit Order Books (LOBs).

- **AMM vs. Order Book Liquidity:**
  - *LOBs:* Liquidity is provided by active market makers and limit orders placed by traders at discrete price levels. Market depth refers to the volume available at the best bid/ask and subsequent price levels.[59] Trading consumes this discrete liquidity, causing prices to jump between levels.
  - *AMMs (including Distribution Markets):* Liquidity is provided passively by LPs who deposit assets into a pool governed by a mathematical invariant (e.g., $||f||_2 = k$).[3] There is technically liquidity at *every* price along the curve defined by the invariant, although the *amount* of liquidity (or depth) varies. Trades move the market state along this continuous curve.[59]
- **Price Impact Models:**
  - *LOBs:* Price impact depends on the trade size relative to the depth available at successive price levels in the order book. Large trades "walk the book," consuming liquidity and moving the price discretely.
  - *AMMs:* Price impact (slippage) is determined by the trade size relative to the pool's reserves and the *curvature* of the trading function.[50] Steeper curves imply lower liquidity and higher price impact for a given trade size. The continuous nature leads to smoother price impact than LOBs, but AMMs are susceptible to *Loss-Versus-Rebalancing (LVR)* or impermanent loss.[50] Because AMMs passively provide liquidity based on their current state, informed arbitrageurs can trade against the pool when its price deviates from the "true" market price (e.g., on a CEX), extracting value from LPs.[50]

- **Market Depth Characterization:**
    - *LOBs:* Depth is measured by the volume of buy/sell orders at various price levels away from the midpoint.
    - *AMMs:* Depth is related to the total value locked (TVL) or reserves in the pool and the specific AMM formula. In MSRs, the liquidity parameter *b* controls depth; a higher *b* means less price impact for a given trade size (more depth).[89] In the Paradigm model, the backing collateral *b* serves a similar role.[3] More generally, market depth in AMMs can be characterized by the *marginal liquidity* – the slope of the demand curve implied by the AMM function at the current price, indicating how much the AMM trades in response to infinitesimal price changes.[50] Flatter bonding curves (lower curvature) correspond to higher marginal liquidity.[50] Concentrated liquidity AMMs (like Uniswap v3) allow LPs to provide depth within specific price ranges, potentially mimicking LOB depth more closely in those ranges.[50]

The fundamental difference lies in the nature of liquidity provision: active and discrete in LOBs versus passive and continuous (along a curve) in AMMs. AMM liquidity is path-dependent, determined by the invariant function, while LOB liquidity is state-dependent, determined by the current set of orders. This leads to smoother price impact in AMMs but exposes passive LPs to adverse selection (LVR), a cost that active LOB market makers can mitigate by adjusting quotes more dynamically. Distribution markets inherit these AMM liquidity characteristics.

6.4. Settlement Mechanisms

The process by which trades are finalized, ownership is transferred, and funds are exchanged also differs significantly.

- **Distribution Market Settlement:** As discussed in Section 2.4, settlement in blockchain-based distribution markets is expected to be automated via smart contracts, triggered by an oracle reporting the final outcome x_o.[3] Key advantages include:
    - *Speed:* Settlement can be near-instantaneous (seconds or minutes), limited only by blockchain confirmation times.[31]
    - *Atomicity:* The entire settlement (payoff calculation and fund transfer) can occur as a single, indivisible transaction.[98]
    - *Reduced Counterparty/Settlement Risk:* Automation and on-chain collateral minimize the risk of settlement failure or counterparty default during the settlement window.[31]
- **Comparison:**
    - *Traditional Equities/Bonds:* Settlement cycles are typically T+1 or T+2 (trade

date plus one or two business days), involving intermediaries like clearing houses and custodians. This delay introduces settlement risk.
  - *Listed Derivatives (Futures/Options):* Cleared through CCPs, which guarantee trades and manage settlement, significantly reducing counterparty risk.[28] Settlement occurs daily (variation margin) and at expiration.
  - *OTC Derivatives:* Settlement is typically bilateral, based on the terms of the ISDA Master Agreement. Disputes over valuation and settlement amounts are common, especially during crises or defaults.[29] Lack of standardization and intermediaries increases settlement risk and complexity.[106]

Blockchain-based settlement offers potential advantages in speed, efficiency, and risk reduction compared to traditional systems, particularly the complex and often risky bilateral settlement processes in OTC markets.

Table 4: Comparative Analysis of Market Properties

Property	Distribution Markets (Paradigm Model)	Traditional Options/Futures (Exchange Traded)	Traditional OTC Derivatives
Leverage Mechanism	Implicit via payoff shaping; Explicit limited by full collateral	Margin requirements (Initial & Maintenance)	Bilateral collateral agreements; often under-collateralized
Leverage Potential	Low explicit; High implicit on specific features	High (especially Futures)	Varies, can be high but depends on negotiation
Optionality Source	Inherent via shaping payoff function *f(x)* [49]	Explicit purchase of standardized option contracts	Explicit via bespoke option contracts
Convexity Potential	High (direct shaping of *f(x)* for convexity) [116]	High (long options have positive Gamma) [114]	High (customizable)
Liquidity Provision	Passive LPs; Algorithmic (AMM curve) [3]	Active Market Makers; Limit Orders (LOB)	Dealer-intermediated ; Bilateral negotiation

Price Impact Nature	Continuous (slippage along curve); Subject to LVR [50]	Discrete (consuming LOB levels)	Opaque; depends on dealer pricing
Settlement Speed	Near-instantaneous (blockchain time) [98]	Daily (margin); T+ at expiry	Varies (bilateral agreement); can be slow/disputed [30]
Settlement Risk	Low (automated, atomic, on-chain collateral) [31]	Low (CCP guaranteed) [103]	High (bilateral counterparty/operational risk) [29]

7. Critical Evaluation: Limitations and Challenges

While distribution markets offer compelling theoretical advantages and novel capabilities, their practical realization and widespread adoption face significant hurdles. A critical evaluation must acknowledge the theoretical limitations, implementation complexities, potential for misuse, regulatory ambiguities, and computational demands inherent in this new market structure.

7.1. Theoretical and Model Limitations

The theoretical frameworks underpinning distribution markets, such as the Paradigm L2-norm CFMM [3] or MSRs adapted for continuous outcomes, rely on specific assumptions that may not hold in reality.

- **Assumptions:** Models typically assume rational, risk-neutral (or known risk preference) traders who perfectly process information and optimize their positions. Real-world traders exhibit bounded rationality, diverse risk attitudes, and cognitive biases, which can lead to deviations from theoretical predictions.[72] The assumption of a specific invariant (like the L2 norm) or a specific scoring rule (like LMSR or QMSR) dictates the market's pricing dynamics; the optimality of these choices for all possible scenarios is not guaranteed. Furthermore, the models often assume perfect and instantaneous information flow and aggregation, which may be unrealistic, especially in complex or opaque information environments. The reliance on a perfect, incorruptible oracle for outcome resolution is a particularly strong assumption.[3]
- **Model Risk:** The choice of the specific distribution market mechanism itself introduces model risk. Different invariants or scoring rules will lead to different price dynamics, liquidity profiles, and sensitivities.[49] For instance, LMSR provides high liquidity near probability extremes (0 and 1), while QMSR offers uniform

liquidity.[88] The choice between them depends on the desired market characteristics, but an inappropriate choice could lead to market inefficiencies or unintended consequences. If the market restricts traded distributions to specific families (e.g., normal distributions) for computational tractability, this imposes a strong assumption that may not capture the true underlying process, leading to mispricing and ineffective hedging.

7.2. Practical Implementation Challenges

Translating the theory of distribution markets into functional, widely-used platforms involves overcoming substantial practical obstacles.

7.2.1. User Complexity and Cognitive Load

Perhaps the most significant barrier to broad adoption is the inherent complexity for end-users.[67]

- **Conceptual Difficulty:** Trading requires participants to think in terms of probability distributions rather than simple prices or discrete outcomes. Formulating beliefs as a PDF $p(x)$ and understanding how a trade modifies the market's implied distribution $f(x)$ requires a level of mathematical and statistical sophistication far beyond that needed for traditional stock or even standard options trading.[3]
- **Interface Challenges:** Designing user interfaces that allow intuitive interaction with probability distributions is extremely challenging. How does a user visualize their position $f(x)$? How do they specify a desired change $g(x) - f(x)$? Standard charts and order entry forms are inadequate. Tools might involve graphical curve manipulation, parameter input for specific distributions, or simplified order types that abstract away the underlying functional mathematics, but these risk losing expressiveness or introducing new complexities.
- **Cognitive Load:** The mental effort required to understand the market mechanics, formulate distributional beliefs, predict the impact of trades, and manage positions represented by functions is substantial.[218] High cognitive load is known to impair decision-making, reduce usability, and hinder adoption of complex systems.[129]

This inherent complexity suggests that, without significant breakthroughs in user interface design and abstraction layers, distribution markets may remain confined to a niche audience of quantitative professionals (quants, data scientists, sophisticated financial engineers). The cognitive barrier is likely too high for widespread retail participation, limiting potential network effects and overall market liquidity, despite the

theoretical benefits of broader information aggregation.[165]

7.2.2. Market Manipulation Potential

Like all markets, distribution markets are susceptible to manipulation, potentially in novel ways due to their unique structure.

- **Outcome/Oracle Manipulation:** If the event outcome x_0 can be influenced by participants, or if the oracle reporting the outcome can be compromised, the market's integrity is destroyed.[220] This is a known risk in prediction markets, potentially exacerbated for complex events with subjective or hard-to-verify outcomes.[33] Dependence on blockchain oracles introduces vulnerabilities related to data source reliability, network consensus, and potential economic attacks designed to corrupt the reported outcome.[94]
- **Price Manipulation (AMM-Specific):** AMMs are vulnerable to specific types of manipulation:
    - *Flash Loan Attacks:* Attackers can borrow large sums momentarily within a single transaction, execute large trades on the AMM to distort its internal price (the shape of $f(x)$), exploit this distortion in another protocol that uses the AMM as a price feed (oracle manipulation), and repay the loan, all atomically.[96] The continuous nature of distribution markets might be particularly sensitive to such price distortions.
    - *Sandwich Attacks:* Front-running and back-running a victim's trade to profit from the price impact caused by their trade.
- **Strategic Trading/Information Withholding:** Sophisticated traders might strategically place trades not to reflect their true beliefs, but to influence the beliefs or actions of others, or to profit from future trades at more favorable prices after misleading the market initially. This is a known issue in MSRs where traders have multiple trading opportunities.[90] The complexity of distribution markets might offer new avenues for such strategic deception.
- **Wash Trading:** Entities can create artificial volume and distort the perceived distribution $f(x)$ by trading with themselves, potentially through multiple addresses.[69] This is a known problem in less regulated crypto markets, including DEXs, used to inflate perceived liquidity or manipulate prices.[69] Detecting such activity in a market for functions could be challenging.
- **Lessons from Parimutuel:** While large, temporary bets in parimutuel markets often fail to permanently manipulate odds due to market correction [24], the continuous nature and potentially lower liquidity of niche distribution markets might make them more susceptible to temporary price dislocations caused by large trades, even if long-term manipulation remains difficult.

7.2.3. Regulatory Hurdles and Ambiguity

The novel nature of distribution markets creates significant regulatory uncertainty.

- **Legal Classification:** How should contracts traded on distribution markets be classified? Are they swaps or other derivatives subject to CFTC regulation in the US?[70] Could they be considered securities under the Howey test, falling under SEC jurisdiction, especially if marketed as investments? For markets based on non-financial events (e.g., politics, science, sports), could they be classified as illegal gaming or gambling under state or federal law?[226] The ongoing regulatory battles involving platforms like Kalshi and Polymarket highlight this ambiguity.[71] The CFTC is actively reviewing its stance on event contracts and prediction markets.[70]
- **Cross-Jurisdictional Challenges:** Blockchain-based markets operate globally, creating challenges for applying national regulations and enforcing compliance.[229]
- **Investor Protection:** Given the complexity, regulators may impose strict suitability standards or limit access for retail investors, similar to concerns raised about other complex products.[165]

This regulatory fog hinders development and adoption, as platforms face legal risks and potential shutdowns. Establishing clear regulatory frameworks that recognize the unique nature of these markets while ensuring investor protection and market integrity is crucial but likely to be a slow and contentious process.

7.2.4. Computational Intensity and Scalability

Implementing distribution markets, especially for continuous and potentially high-dimensional

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